[Claim 6] An optical switching device according to either one of claims 1 to 5, wherein the time required for switching between input/output paths of input/output ports is 10 ms or less.

[Claim 7] An optical switching device according to either one of claims 1 to 5, wherein, when switching between input/output paths of input/output ports, crosstalk to the other input/output ports is -25 dB or better.

[Claim 8] An optical transmission system comprising the optical switching device according to either one of claims 1 to 7.

[DETAILED DESCRIPTION OF THE INVENTION]

[0001]

[Technical Filed of the Invention]

The present invention relates to an optical switching device and optical transmission system used in wavelength division multiplexing (WDM) optical communications and the like.

[0002]

[Prior Art]

An example of optical switching device used in WDM optical communication systems is a wavelength-selective switch disclosed in Non-patent document 1. This wavelength-selective switch comprises a plurality of I/O ports, each constituted by an optical fiber and a lens, a diffraction grating, and a MEMS mirror which are combined together, thereby making it possible to attain a smaller size and a lower cost.

[0003]

[Non-patent document 1]

OFC 2002 Postdeadline Papers, FB7-1, "Wavelength-selective 1 x 4 switch for 128 WDM channels at 50 GHz spacing"

[0004]

[Problems that the invention is to solved]

However, the following problem exists in the prior art mentioned above. Namely, since the MEMS mirror is driven only in directions for switching between input/output optical paths of input/output ports, optical signals reflected by the MEMS mirror when switching between the input/output optical paths of input/output ports may traverse their adjacent input/output ports. In this case, unnecessary light may enter the latter input/output ports, thereby deteriorating the transmission quality of optical signals passing therethrough.

[0005]

It is an object of the present invention to provide an optical switching device and optical transmission system which can switch between input/output optical paths of input/output ports while suppressing the influence on optical signals passing through other input/output ports.

[0006]

[Means for solving the problems]

An optical switching device of the present invention comprises a plurality of input/output ports for inputting/outputting optical signals, and switching means for

switching between input/output optical paths of the input/output ports. The switching means has an optical member for reflecting an optical signal inputted from any of the plurality of input/output ports toward another of the input/output ports; a first driving means for driving said optical member so as to switch between input/output optical paths of the input/output ports; and a second driving means for driving said optical member so as to displace between a position to reflect the optical signal in a direction toward the input/output port and a position to reflect the optical signal in a direction deviated from the direction toward the input/output port.

[0007]

When switching between input/output paths of input/output ports, the optical member is initially displaced to a position (shunt position) to reflect the optical signal in a direction deviated from the direction toward the input/output port from a position (normal position) to reflect the optical signal in a direction toward the input/output port by the second driving means. Subsequently, the optical member is displaced so as to switch between input/output optical paths of the input/output ports by the first driving means. Thereafter, the optical member is displaced to the normal position from the shunt position by the second driving means. Thus, the optical member is displaced to the shunt position in advance by the second driving means, and then driven to switch between input/output optical paths of the input/output ports by the first driving means. This prevents

the optical signal reflected by the optical member from traversing other input/output ports which are not subjected to switching while switching between input/output paths of input/output ports. Hence, the light leaking to the other input/output ports is reduced, whereby influences on optical signals passing therethrough can be alleviated.

[0008]

An optical switching device preferably comprises an optical demultiplexer device for demultiplexing a wavelength division multiplexing optical signal into individual wavelengths. The switching means preferably has a plurality of optical members corresponding to respective signal light components demultiplexed into the individual wavelengths. This allows the optical switching device to be used as a wavelength-selective switch, whereby an optical ADM (Add Drop Multiplexer) for adding/or dropping a signal having a given wavelength to/from a wavelength-division-multiplexed optical signal and the like can be realized in a simple configuration.

[0009]

The optical member is preferably provided inclinably on a cantilever supported by a base substance. The first driving means preferably tilts the optical member with respect to the cantilever. The second driving means preferably displaces the optical member in a direction different from the tilting direction of the optical member. As a consequence, the switching means having the optical member, the first driving means, and the second driving means

can be realized in a simple configuration.

[0010]

The first driving means preferably has a first electrode provided on said base substance and a first voltage source to apply a voltage to the first electrode. The second driving means preferably has a second electrode provided on said base substance and a second voltage source to apply a voltage to the second electrode. This allows the optical member to be displaced by an electrostatic force, so that substantially no current is required to flow, whereby power can be saved.

[0011]

An optical switching device of the present invention comprises a plurality of input/output ports for inputting/outputting optical signals, and switching means for switching between input/output optical paths of the input/output ports. The switching means switches between the input/output optical paths of the input/output ports so as to keep an optical signal led to any of the plurality of input/output ports from traversing other input/output ports.

[0012]

Since this optical switching device is configured such that, when switching between input/output optical paths of input/output optical ports, an optical signal does not traverse other input/output ports which are not subjected to switching, light leaking to the other input/output ports is reduced, whereby influences on optical signals passing therethrough can be

alleviated.

[0013]

The time required for switching between input/output paths of input/output ports is preferably 10 ms or less. This makes it less likely for light to leak into other input/output ports which are not subjected to switching, whereby influences on optical signals passing therethrough can further be alleviated.

[0014]

When switching between input/output paths of input/output ports, crosstalk to the other input/output ports is preferably -25 dB or better. In this case, there are substantially no influences on optical signals passing through other input/output ports which are not subjected to switching.

[0015]

An optical transmission system of the present invention comprises the above-mentioned optical switching device. As a consequence, as mentioned above, when switching between input/output optical paths of input/output optical ports in the optical switching device, influences on optical signals passing through other input/output ports which are not subjected to switching can be alleviated.

[0016]

[Preferred embodiment of the invention]

In the following, preferred embodiments of the optical switching device and optical transmission system in accordance with the present invention will be explained with reference to

the drawings.

[0017]

Figs. 1 and 2 are schematic diagrams showing the optical switching device in accordance with an embodiment of the present invention. For convenience of explanation, an xyz orthogonal coordinate system and an xy'z' orthogonal coordinate system are shown in each of the drawings. Fig. 1 is a view showing the optical switching device in y- and y'-axis directions, whereas Fig. 2 is a view showing the optical switching device in the x-axis direction.

[0018]

In each diagram, the optical switching device 1 in accordance with this embodiment comprises a plurality of input/output optical fibers 2a to 2f, an array lens 3, a diffraction grating 4, a lens 5, and an optical switch array 6. The xyz orthogonal coordinate system is used in the optical system between the input/output optical fibers 2a to 2f and the diffraction grating 4, whereas the xy'z' orthogonal coordinate system is used in the optical system between the diffraction grating device 4 and the optical switch array 6.

[0019]

The input/output optical fibers 2a to 2f are input/output ports for inputting/outputting an optical signal (wavelength division multiplexing optical signal) in which four wavelengths λ_1 to λ_4, for example, are multiplexed, and are arranged in parallel with the z-axis direction. The input/output optical fiber 2c

is used as a common entrance port, whereas the input/output optical fiber 2d is used as a common exit port. The input/output optical fibers 2a, 2e are used as Add ports, whereas the input/output optical fibers 2b, 2f are used as Drop ports.

[0020]

The array lens 3 collimates optical signals inputted from the input/output optical fibers 2a, 2c, 2e and outputs thus collimated optical signals to the diffraction grating 4, and converges optical signals from the diffraction grating 4 and outputs thus converged optical signals to the input/output optical fibers 2b, 2d, 2f.

[0021]

The diffraction grating 4 diffracts the wavelength division multiplexing signal light from the array lens 3 at respective diffraction angles corresponding to the wavelengths λ_1 to λ_4, so as to demultiplex the wavelength division multiplexing signal light into the wavelengths λ_1 to λ_4, and outputs thus demultiplexed optical signals to the lens 5. Though the depicted diffraction grating 4 is of transmission type, diffraction gratings of reflection type may also be used.

[0022]

The lens 5 converges the respective optical signals having wavelengths of λ_1 to λ_4 demultiplexed by the diffraction grating 4 and outputs thus converged optical signals to the optical switch array 6, and collimates optical signals from the optical switch array 6 and outputs thus collimated optical signals to the

diffraction grating 4.

[0023]

The optical switch array 6 comprises movable mirrors 7a to 7d (which may collectively be referred to as a movable mirror 7 hereinafter) for reflecting the respective optical signals having the wavelengths of λ_1 to λ_4 converged by the lens 5, and switches between input/output optical paths of the input/output optical fibers 2a to 2f.

[0024]

Fig. 3 is a plan view showing a part of the optical switch array 6, whereas Fig. 4 is a sectional view taken along the line IV-IV of Fig. 3. In each of these drawings, the optical switch array 6 comprises a substrate 8 made of Si or the like, and a plurality of actuator parts 9 formed on the substrate 8 by using a microelectromechanical systems (MEMS) technology.

[0025]

Each actuator part 9 comprises a cantilever 11, one end of which is supported in a cantilever fashion on the upper face of the substrate 8 by way of a spacer 10, whereas an annular support 12 is provided in a part of the cantilever 11 on the leading end side. The annular support 12 supports the movable mirror 7 by way of hinges 13 on both sides thereof. The hinges 13 extend longitudinally of the cantilever 11, whereby the movable mirror 7 can tilt with respect to the axis (y'-axis) parallel to the longitudinal direction of the cantilever 11 (see Fig. 6). The leading end of the cantilever 11 is provided with a comb part

14.

[0026]

At a location opposing the movable mirror 7, the upper face of the substrate 8 is provided with a pair of substantially semicircular electrodes 15a, 15b for tilting the movable mirror 7 with respect to the annular support 12 as shown in Fig. 5. At a location in the vicinity of the comb part 14, the upper face of the substrate 8 is provided with a comb-shaped electrode 16 for flexing the cantilever 11 to displace the movable mirror 7 in a direction different from the tilting direction of the movable mirror 7.

[0027]

Such an actuator part 9 is formed from electrically conductive Si, for example. The reflecting surface of the movable mirror 7 is coated with Au, for example, in order to reflect substantially all the light from the lens 5.

[0028]

The cantilever 11 is connected to the electrodes 15a, 15b by way of a voltage source 17. When the voltage source 17 supplies a voltage to the electrodes 15a, 15b, an electrostatic force is generated between the movable mirror 7 and the electrodes 15a, 15b, so as to tilt the movable mirror 7 with respect to the annular support 12 of the cantilever 11.

[0029]

When the voltage applied to the electrodes 15a, 15b is zero, the movable mirror 7 is parallel to the annular support 12 as

shown in Fig. 6(a). In this state, the movable mirror 7 reflects the optical signal from the input/output optical fiber (common entrance port) 2c toward the input/output optical fiber (common exit port) 2d.

[0030]

When a predetermined voltage is applied to the electrode 15a, an electrostatic force generated between the movable mirror 7 and the electrode 15a attracts a part of the movable mirror 7 on the electrode 15a side toward the electrode 15a, whereby the movable mirror 7 tilts with respect to the annular support 12 as shown in Fig. 6(b). In this state, the movable mirror 7 outputs the optical signal from the input/output optical fiber (common entrance port) 2c toward the input/output optical fiber (Drop port) 2f.

[0031]

When a predetermined voltage is applied to the electrode 15b, an electrostatic force generated between the movable mirror 7 and the electrode 15b attracts a part of the movable mirror 7 on the electrode 15b side toward the electrode 15b, whereby the movable mirror 7 tilts with respect to the annular support 12 in the opposite direction as shown in Fig. 6(c). In this state, the movable mirror 7 outputs the optical signal from the input/output optical fiber (common entrance port) 2c toward the input/output optical fiber (Drop port) 2b.

[0032]

The cantilever 11 and the electrode 16 are connected to

each other by way of a voltage source 18. The voltage source 18 supplies a voltage to the electrode 16, so as to generate an electrostatic force between the comb part 14 and the electrode 16, thereby flexing a part of the cantilever 11 on the leading end side downward.

[0033]

When the voltage applied to the electrode 16 is zero, the cantilever 11 is straight as shown in Fig. 4. In this state, the movable mirror 7 is at a normal position for reflecting the optical signals led from the input/output optical fibers 2a, 2c, 2e by way of the array lens 3, diffraction grating 4, and lens 5 toward the input/output optical fibers 2b, 2d, 2f by way of the lens 5, diffraction grating 4, and array lens 3.

[0034]

When a predetermined pulse voltage is applied to the electrode 16, on the other hand, an electrostatic force generated between the comb part 14 and the electrode 16 attracts the comb part 14 toward the electrode 16, so that a part of the cantilever 11 on the leading end side flexes downward, thereby displacing the movable mirror 7 in the direction different from the tilting direction of the movable mirror 7 (See Fig. 6(b)) as shown in Fig. 7. As a consequence, the movable mirror 7 moves to a shunt position for reflecting the optical signals led from the input/output optical fibers 2a, 2c, 2e by way of the array lens 3, diffraction grating 4, and lens 5 away from the input/output optical fibers 2b, 2d, 2f.

[0035]

Operations of thus configured optical switching device 1 will now be explained. The wavelength division multiplexing optical signal inputted from the input/output optical fiber (common entrance port) 2c is collimated by the array lens 3, so as to be made incident on the diffraction grating 4, by which the optical signal is demultiplexed into the individual wavelengths λ_1 to λ_4. The respective optical signals having the wavelengths λ_1 to λ_4 are reflected by the movable mirrors 7a to 7d of the optical switch array 6 while in a state converged by the lens 5.

[0036]

When the voltage applied from the voltage sources 17, 18 to the optical switch array 6 is zero here, the movable mirrors 7a to 7d are at the normal position (posture) as shown in Fig. 4, whereby their angle of inclination is zero degree as shown in Fig. 6(a).

[0037]

In this case, the respective optical signals reflected by the movable mirrors 7a to 7d are made incident on the diffraction grating 4 and multiplexed thereby while in a state collimated by the lens 5. Thus multiplexed optical signal is outputted from the input/output optical fiber (common exit port) 2d while in a state converged by the array lens 3. As a consequence, the wavelength division multiplexing optical signal inputted from the input/output optical fiber 2c is outputted as it is from the

input/output optical fiber 2d at the time of power failure.

[0038]

When wavelength switching is effected here so as to make the input/output optical fiber (Drop port) 2b output only the optical signal having the wavelength λ_4 in the wavelength division multiplexing optical signal inputted from the input/output optical fiber 2c, for example, the voltage source 18 initially applies a pulse voltage to the electrode 16 in the actuator part 9 having the movable mirror 7d for reflecting the optical signal having the wavelength λ_4. Consequently, as shown in Fig. 7, the leading end side of the cantilever 11 in the actuator part 9 flexes downward, whereby the movable mirror 7d shifts from the normal position to the shunt position. As a consequence, the optical axis of the optical signal having the wavelength λ_4 reflected by the movable mirror 7d deviates from the optical axes of the optical signals having the wavelengths λ_1 to λ_3 reflected by the movable mirrors 7d. Therefore, the optical signal having the wavelength λ_4 reflected by the movable mirror 7d is not made incident on the lens 5, and thus does not reach the input/output optical fiber 2d.

[0039]

In this state, the voltage source 17 applies a predetermined voltage to the electrode 15b in the actuator part 9 having the movable mirror 7d, so as to tilt the movable mirror 7d in the direction shown in Fig. 6(c), thereby choosing the input/output optical fiber 2b as an output port for the optical signal having

the wavelength λ_4.

[0040]

Subsequently, the voltage applied to the electrode 16 is set to zero. As a consequence, the cantilever 11 resumes its initial state as shown in Fig. 4 because of its urging force, whereby the movable mirror 7d returns from the shunt position to the normal position. As a result, the optical signal having the wavelength λ_4 reflected by the movable mirror 7d is outputted from the input/output optical fiber 2b while in a state collimated by the lens 5, diffracted by the diffraction grating 4, and converged by the array lens 3.

[0041]

When the actuator part 9 lacks the comb part 14, electrode 16, and voltage source 18, tilt angle of the movable mirror 7d changes while being held at the normal position shown in Fig. 4 in the above-mentioned wavelength switching. Namely, while the optical signal having the wavelength λ_4 reflected by the movable mirror 7d is incident on the input/output optical fiber 2d, the output optical path of the optical signal having the wavelength λ_4 is switched from the input/output optical fiber 2d to the input/output optical fiber 2b.

[0042]

In this case, the optical signal having the wavelength λ_4 reflected by the movable mirror 7d traverses the input/output optical fiber (common entrance port) 2c between the input/output optical fibers 2d, 2b, whereby an unnecessary optical signal may

enter the input/output optical fiber 2c. This may affect the optical signal passing through the input/output optical fiber 2c, thereby remarkably deteriorating the transmission quality.

[0043]

In this embodiment, by contrast, the movable mirror 7d is shifted from the normal position shown in Fig. 4 to the shunt position shown in Fig. 7, and tilt angle of the movable mirror 7d is changed in this state. As a consequence, the optical signal having the wavelength λ_4 reflected by the movable mirror 7d does not traverse the input/output optical fiber 2c when switching the output optical path from the input/output optical fiber 2d to the input/output optical fiber 2b. Therefore, unnecessary light hardly leaks into the input/output optical fiber 2c, whereby the optical signal passing through the input/output optical fiber 2c can be prevented from deteriorating.

[0044]

In order to prevent light from leaking into the input/output optical fiber 2c more reliably, it is preferred that the time required for switching between input/output optical paths be 10 ms or less. When switching between input/output paths, it is preferred that the intensity of the optical signal leaking to the input/output optical fiber 2c (crosstalk to the input/output optical fiber 2c) be −25 dB or better.

[0045]

Fig. 8 shows the configuration of an optical ADM as an example of optical transmission system comprising the above-mentioned

optical switching device 1.

[0046]

The optical ADM 20 shown in this drawing comprises the above-mentioned optical switching device 1. A multiplexer 21 is connected to the input/output optical fiber 2c of the optical switching device 1. A demultiplexer 22 is connected to the input/output optical fiber 2d of the optical switching device 1. The multiplexer 21 combines respective optical signals having individual wavelengths, and leads thus multiplexed signals into one input/output optical fiber 2c. The demultiplexer 22 demultiplexes a plurality of optical signals having different wavelengths propagated through one input/output optical fiber 2d into the individual wavelengths. Multiplexers 23 for adding are connected to the input/output optical fibers 2a, 2e of the optical switching device 1, respectively. Demultiplexers 24 for dropping are connected to the input/output optical fibers 2b, 2f of the optical switching device 1, respectively.

[0047]

Providing the optical switching device 1 as such makes it unnecessary to construct an optical ADM by using numerous m x n optical switches. This allows the optical ADM to become smaller, simpler, and less expensive.

[0048]

The present invention is not restricted to the above-mentioned embodiments. For example, though a mirror is used as an optical member for reflecting optical signals from

the lens 5 in the above-mentioned embodiments, a prism may be used in place of the mirror.

[0049]

Though the substrate 8 is provided with the electrodes 15a, 15b, 16 so that the movable mirror 7 is driven by electrostatic forces in the above-mentioned embodiments, electromagnetic forces may be used for driving the movable mirror 7.

[0050]

Though a plurality of input/output ports for inputting/outputting optical signals are constituted by optical fibers in the above-mentioned embodiments, they may be constructed by planar waveguides as well.

[0051]

Though the above-mentioned embodiments employ the optical switching device in an optical ADM, the optical switching device of the present invention can be employed for optical multi/demultiplexers as well. The optical switching device of the present invention is applicable not only to wavelength-selective switches, but also to others as long as they are adapted to switch between input/output paths of input/output ports.

[0052]

[Effect of the invention]

A switching device of the present invention comprises a first driving means for driving a optical member so as to switch between input/output optical paths of the input/output ports;

and a second driving means for driving the optical member so as to displace between a position to reflect an optical signal in a direction toward the input/output port and a position to reflect the optical signal in a direction deviated from the direction toward the input/output port. As a result, when switching between input/output optical paths of input/output optical ports, influences on optical signals passing through other input/output ports which are not subjected to switching can be alleviated.

[BRIEF EXPLANATION OF THE DRAWINGS]

[Fig. 1]

A schematic diagram of the optical switching device in accordance with an embodiment of the present invention as seen in y- and y'-axis directions.

[Fig. 2]

A schematic diagram of the optical switching device in accordance with the above-mentioned embodiment of the present invention as seen in the x-axis direction.

[Fig. 3]

A plan view showing a part of the optical switch array shown in Figs. 1 and 2.

[Fig. 4]

A sectional view taken along the line IV-IV of Fig. 3.

[Fig. 5]

A plan view of the substrate shown in Fig. 3.

[Fig. 6]

A sectional view showing a state where a movable mirror

is tilted with respect to the annular support.

[Fig. 7]

A sectional view showing a state where the cantilever is flexed so as to displace the movable mirror.

[Fig. 8]

A diagram showing an optical ADM as an example of optical transmission system equipped with the optical switching device shown in Figs. 1 and 2.

[Explanation of reference numerals]

1 Optical switching device

2a to 2f Input/output optical fiber (Input/output port)

3 Array lens

4 Diffraction grating (Optical demultiplexer device)

5 Lens

6 Optical switch array

7, 7a to 7d Movable mirrors (Switching means)

8 Substrate (Base substance)

11 Cantilever

12 Annular support

13 Hinge

14 Comb part

15a, 15b Electrode (First electrode, First driving means)

16 Electrode (Second electrode, Second driving

means)

17 Voltage source (First voltage source, First driving means)

18 Voltage source (Second voltage source, Second driving means)

20 Optical ADM (Optical transmission system)